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Evaluating the Success of Natural Regeneration in Partially Cut Douglas-Fir Stands in Southeastern British Columbia: A Retrospective Investigation

Technical Report TR-018

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Forest Sciences, Nelson Forest Region, BCMOF

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EXECUTIVE SUMMARY

This report summarizes the results of a retrospective study of post-harvest conditions in the Kootenay variant of the Interior Douglas-Fir Dry Mild biogeoclimatic subzone (IDFdm2) in the Rocky Mountain Trench of the Nelson Forest Region. The 22 stands in the study were harvested by partial cutting methods between 1982 and 1992. The study, initiated in 1998, was undertaken to assist forest managers in preparing forest development plans that, increasingly, include partial cutting.

The objectives of the study were to:

1) Evaluate the success of advanced and post-harvest natural regeneration.

2) Evaluate the effects of overstory and site conditions, and relate them to regeneration success.

3) Assess early stand development and release of the residual stand.

Generally, with the exception of droughty south-facing slopes, these stands are well stocked. Post-harvest natural regeneration (counting only Layer 4 stems) was generally abundant, ranging from 189 to 5067 stems/ha. The understory species composition reflected that of the remaining overstory species composition within 3%.

There was no significant correlation between basal area retained and numbers of germinants. However, together, shrub cover, slash cover, and residual stems/ha accounted for 54% of the variation in germinants.

Harvesting removed 13 to 70% of the pre-harvest basal area. Post-harvest basal area growth averaged 0.31 m^2/ha/yr, and the stands assessed are expected to take between 11 and 90 years to recover to their respective pre-harvest basal areas.

The silviculture prescriptions for most of the study stands specified salvaging lodgepole pine due to mountain pine beetle infestation. As such, the stands were not planned as partial cuts. Since that time, the Forest Practices Code of British Columbia has been enacted. Therefore, the authors suggest that the findings from this study may not be representative of current harvesting or silvicultural practices.

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Numerous people have contributed to this project. We would like to thank the following for their assistance: Gaetan Effray and the crew at Strategic Silviculture Ltd.; Bill Olsen, Megan Williams, Denis Petryshen, and Steve Byford of the Cranbrook Forest District, BCMOF; Debbie Waterer, Emile Begin, Darrell Regimbald, and Fred Waterer of the Invermere Forest District, BCMOF; and Rick Logan, Mike Curran, and Deb DeLong of the Nelson Forest Region, BCMOF. Heather Pinnell of H. Pinnell Forestry Consulting, Ken Day of the University of British Columbia, and Barry Snowdon from the BCMOF's Silviculture Practices Branch also made significant contributions to the development of this report. Alan Vyse, Research Forester, at the Kamloops Forest Region of the BCMOF, provided thoughtful comments on the report. Forest Renewal BC provided funding, which was administered by the Science Council of BC.

1.0 INTRODUCTION

Although partial cutting in Interior Douglas-Fir (IDF) (Braumandl and Curran 1992) forests in British Columbia (BC) has occurred for many years, the natural stand regeneration and growth dynamics of these stands have been studied only recently. Most of the previous studies were done in the Fraser variant of the Interior Douglas-Fir Dry Cool biogeoclimatic subzone (IDFdk3) and the Interior Douglas-Fir Very Dry Mild subzone (IDFxm) of the Cariboo Forest Region (Steen and Coupe 1997). Studies concerning regeneration on dry sites have also been done in the United States. However, little research exists on the regeneration and growth dynamics of partially cut IDF stands in the Kootenay region of southeastern British Columbia.

Partial cutting is increasingly included in forest development plans, in large part due to the implementation of the *Forest Practices Code of BC Act* in 1995. The Forest Practices Code legislates the management of non-timber values such as wildlife, recreation, visuals, and water quality, thus putting additional pressure on forest managers to use partial cutting methods. In 1998, the Forest Sciences Section of the Nelson Forest Region (BC Ministry of Forests), initiated a retrospective study of natural regeneration and stand dynamics in partially cut stands in the Kootenay variant of the IDF Dry mild biogeoclimatic subzone (IDFdm2) (Braumandl and Curran 1992). The results from this study were intended to assist foresters in preparing future forest prescriptions that include partial cutting. The study focussed on IDFdm2 stands in the Nelson Forest Region that were partially cut between 1982 and 1992. The results, presented in this report, are compared to findings from other Forest Regions in BC and to appropriate ecozones in the United States.

2.0 ECOLOGY AND RECENT HISTORY OF THE IDFdm2

The IDF biogeoclimatic zone comprises 500 000 ha of the Nelson Forest Region's 8.2 million ha productive forest land. The Kootenay variant of the Dry Mild subzone, the IDFdm2, makes up 65% or, 324 000 ha of this subzone.

The IDFdm2 is found on valley bottoms and lower slopes of the Rocky Mountain Trench from slightly north of Golden, BC to south of Canada's border with the United States (FIGURE 1).

The IDFdm2 is located at elevation ranges of 800 to 1200 m on south aspects, and from 800 to 1100 m on north aspects. The zone falls within the Dry Climatic Region where summers are hot and very dry, and soils generally dry out for at least a short period of time during the later summer. Winters are cool and the shallow snow packs usually last only briefly. This allows the soils to freeze to at least a shallow depth on some sites. The major limiting site factors to tree growth include frost and lack of soil moisture (Braumandl and Curran 1992). Soils are often of a calcareous nature, usually underlain by deep, recent sediments. Soils may also have strongly contrasting textures at depth (Braumandl and Curran 1992).

Although the warm and dry sites in the subzone are occupied by Douglas-fir, this species shares potential climax status with the even more drought-tolerant ponderosa pine (Arno 1991; Braumandl and Curran 1992). The ponderosa pine / Douglas-fir stands often remained comparatively open, even with fire suppression, due to drought and inherent stocking limitations (Arno 1991). Sites warmer and drier than these are characterized by pure ponderosa pine (Arno 1991; Braumandl and Curran 1992). Zonal sites have climax stands of Douglas-fir; however, mixed seral stands of Douglas-fir, western larch, and lodgepole pine are more common.

Prior to 1900, most of the IDFdm2 experienced frequent natural fires, was probably dominated by ponderosa pine, and western larch was likely more prevalent than today (Arno et al. 1997). Active fire suppression started in 1947[1].

Most of the stands in the study were harvested by 1950, either for railway ties or for lumber. Since then, most stands have experienced few if any fires; as a result, the more shade-tolerant Douglas-fir has become dominant (Arno 1997). Thus, all the study stands were probably burned, harvested, and then protected from fire for 40 years prior to the current cycle of harvesting (1982-1992). Additionally, all the study sites were grazed by cattle.

Only a small percentage of ponderosa pine and western larch existed in the study stands prior to recent harvesting. Substantial quantities of the lodgepole pine in the study stands likely initiated after 1900 in response to bark beetle infestations and subsequent fires. Fire suppression since then has likely favoured both Douglas-fir and lodgepole pine (Burns and Honkala 1990).

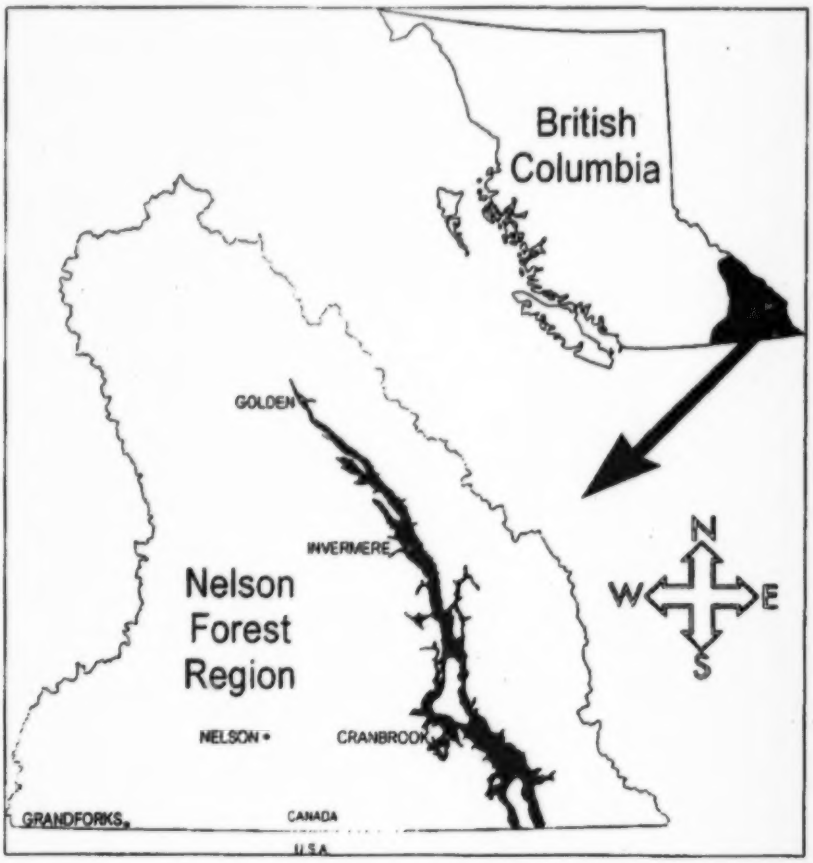

FIGURE 1. Location of the Kootenay variant of the Interior Douglas-Fir Dry Cool biogeoclimatic zone (IDFdm2) in the Nelson Forest Region in southeastern BC.

[1] M. Houlind, Forest Protection Technician, Cranbrook Forest District, BCMOF; personal communication, 1998.

3.0 OBJECTIVES

The general objective of this study was to examine stands in the IDFdm2 that had been partially cut between 1982 and 1992 to assess the post-harvest stand structure.

The specific objectives of this study were to:

1. Evaluate advanced and post-harvest natural regeneration.
2. Evaluate the effects of overstory and site conditions, and relate them to natural regeneration success.
3. Assess early stand development and release of the residual stand.

Issues concerning cattle grazing or cattle exclusion were not within the scope of this project.

4.0 METHODS

4.1 Site Selection Criteria

The criteria for selecting the study sites were:

1. The site was located in the IDFdm2 biogeoclimatic subzone in either the Cranbrook or Invermere Forest Districts of the Nelson Forest Region.
2. The site had been harvested between 1982 and 1992.
3. The opening or stratum was at least 5 ha.
4. Adequate historical information about harvest method and pre-harvest stand conditions was available.
5. The opening was reasonably homogeneous with respect to site and treatment factors.
6. No spacing or "stand improvements", such as fertilization or culturing/pruning for Christmas trees, had occurred.
7. The site had been partially cut (ideally, having an average of >12 m^2/ha of basal area).

The goal was to select 10-20 stands with moderate levels of harvesting, and thus with moderate environmental changes. Stands with 20 to 80% of the basal area removed were considered to meet this goal (Butt and Bancroft 1990). A minimum of 12 m^2/ha was considered to represent the lower end of this range (Butt and Bancroft 1990), although some sites with <12 m^2/ha were accepted for study.

4.2 Site Selection Methodology

The Cranbrook and Invermere Forest Districts each provided a list of all partially cut openings from the Integrated Silviculture Information System (BCMOF 1997a). These reports included descriptions of openings that were recorded as having been harvested under the following systems:

i) Seed tree ii) Selective

iii) Shelterwood iv) Diameter limit

The reports listed approximately 280 openings in the Cranbrook Forest District and 87 in the Invermere Forest District. From these lists, suitable areas were found by consulting with District

staff, scanning air photos, and investigating any block that looked remotely suitable. Thirty-five areas were selected for field review.

Many potential sites were discarded after field inspection. The main reason for rejection was that the sites looked more like a clearcut than a partially cut stand; their basal areas averaged <12m^2/ha. In the Invermere Forest District, suitable sites were particularly difficult to find because most of the sites had been converted to Christmas tree permits after harvesting. Another reason for rejection was incomplete history information, usually for those sites harvested between 1982 and 1987, prior to the implementation of Pre-Harvest Silviculture Prescriptions.

Ultimately, 13 sites were selected: 11 in the Cranbrook Forest District, and 2 in the Invermere District (TABLE 1). This meant that most of the study sites were situated in the southern third to half of the IDFdm2. Because ponderosa pine is more prevalent in the southern portion of the IDFdm2 than in the northern portion (Braumandl and Curran 1992), the study sites were skewed to sites ecologically more suited to ponderosa pine. Most areas had been harvested under the Small Business Forest Enterprise Program.

Most study sites were in the zonal 01 FdPl - Pinegrass-Twinflower and, 03 Fd - Snowberry-Balsamroot site series (Braumandl and Curran 1992). The hottest southern aspects are notoriously difficult to regenerate, and these sites were not assessed. Where natural regeneration failed in these subzones, it has likely been due to extreme temperature and drought (Williamson 1973).

TABLE 1. Description of study sites.

Study Unit	Opening number	Location	Stratum	Area (ha)	Total plots (no.)
1	82G041 - 57	Peavine Road	A	25.0	18
2	82G024 - 37	Teepee Road	A	19.9	18
			B	34.3	32
			C	18.7	18
3	82G024 - 07	Teepee Road	A	10.0	9
			B	6.0	6
4	82G034 - 140	Sand Creek, south	A	8.4	10
5	82G035 - 43	Sand Creek, south	A	22.6	22
			B	16.0	16
			C	14.2	12
			D	16.5	13
6	82G061 - 36	Kimberly	A	17.0	16
7	82G071 - 14	Lost Dog / Tata Lake	A	5.0	9
			B	5.0	9
8	82G071 - 40	Lost Dog / Tata Lake	A	8.0	10
9	82G071 - 48	Lost Dog / Tata Lake	A	16.0	16
			B	13.0	12
10	82G034 - ?	Sand Creek, east	A	12.0	12
11	82K070 - 24	Invermere	A	13.1	12
			B	16.3	9
12	82J012 - 17	Whiteswan	A	18.1	17
13	82G071 - 49	Lost Dog / Tata Lake	A	21.0	19
Total					315

4.3 Location and Distribution of Sample Plots

Where necessary, each selected opening was divided into strata. Each stratum was relatively uniform in terms of residual basal area, vegetation cover, and site series.

A survey grid was laid out within each stratum.

- Plots were gridded at 100x100-m intervals. In strata up to 20 ha in size, 1 plot/ha was established. For areas larger than 20 ha, the grid was widened and 1 plot/2 ha was established. The minimum number of plots/stratum was five.
- In general, plots were located:
  - A maximum of one tree length away from at least one Layer 1 tree.
  - A maximum of 10 m away from at least one stump.
- Thus, all sampling points were located in an area affected by partial cutting, while preferably not being in a "clearcut" environment (after Butt and Bancroft 1990).
- The same plot centre was used for three nested plots (FIGURE 2).

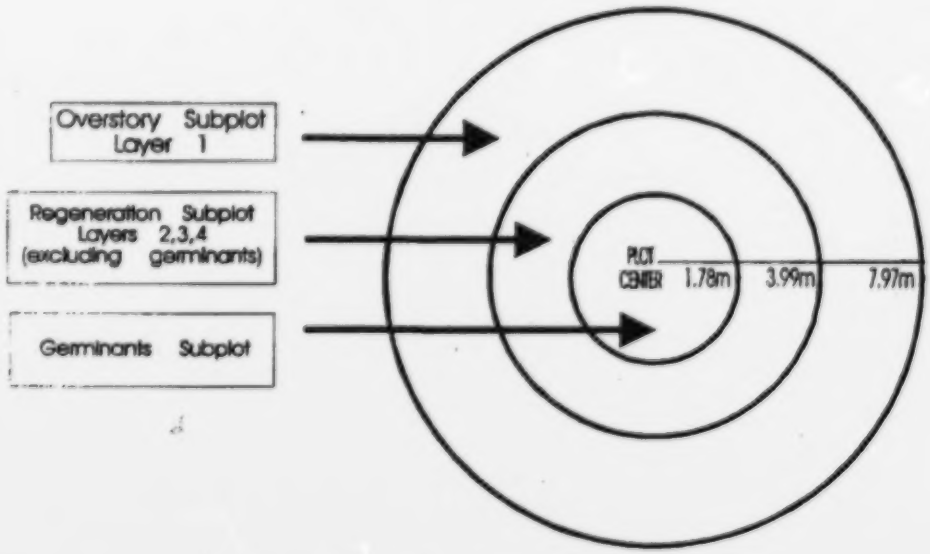

FIGURE 2. Schematic of nested sample plots.

4.4 Measurements

Measurements were taken at each subplot by parameter as listed below. Unless otherwise stated, measurements conformed to the current BCMOF Cruising Manual (TABLE 2).

At each plot, measurements were made in nested subplots according to layers numbered 1 through 4 (Butt and Bancroft 1990; Catton 1997; and DeLong 1997) (TABLE 2).

TABLE 2. Definitions by layer.

Layer	Layer name	Description of layer
1	Mature	≥12.5-cm dbh
2	Pole	7.5 to 12.49-cm dbh
3	Sapling	1.3-m high to 7.49-cm dbh
4	Regeneration	<1.3-m high
	Germinants	Seedlings <2-yr old

Measurements taken in the overstory subplot (radius = 7.97 m) for all stems >12.5 cm dbh (Layer 1):

- Tree number, species, diameter at breast height (dbh), and height.
- Age and radial increment (in cm) since harvest date were taken for 2 trees/plot. Usually, there were very few (1-3) sample trees from which to chose. Where there were more Layer 1 trees to select from, the sample trees were to be healthy, and judged to be representative of the residual stems. Also, the number of trees sampled reflected funding limits for the project. Determining the age of all trees by drilling cores, or by cutting down the smaller trees to count the rings, was too time consuming and costly.
- Estimate of percent crown closure (densiometer was used).
- Percent live crown.
- Harvesting damage (area of bark removal, in cm^2).
- Forest health agents (usually incidence of *Armillaria*).
- Count and measure diameter (outside bark) of stumps at the cut height of 0.3 m by species (to estimate pre-harvest stocking). Where stump heights were <0.3 m, the data were converted in the office to a stump height of 0.3 m (Omule and Kozak 1989).
- Dbh and species (if known) of all snags.
- Count by species of post-harvest windthrown trees originating in plot, a blowdown stem was treated and measured as if it were a snag.

Measurements taken in the regeneration subplot (radius = 3.99 m) for Layers 2, 3, and 4, excluding germinants <2 years old:

- The following origins were used in Layers 3 and 4:
  - — Natural/post-harvest (established since harvest date).
  - — Natural/advanced regeneration (present at time of harvest date).
- Total trees by species and origin (natural or advanced regeneration).
- Total well-spaced stems.
- Forest health agents (usually number of stems/layer with signs of *Armillaria*).
- Estimated height, age, leader growth, vigour (good, medium, poor) by layer, by species, and by origin.

- For two of each layer for each origin per plot: age, total height, and length of preceding five internodes.
- Dbh of all Layer 2 and Layer 3 trees.
- Estimated average percent live crown by species by layer (percent live crown on representative individual).

Measurements taken in the germinant / vegetation subplot (radius = 1.78 m) for germinants <2 years old:

- Germinant total, species, height, condition.
- Seedbed (mineral, mixed, undisturbed, rotted wood).
- Percent cover of slash and vegetation by major species (ocular estimate).
- Modal height of vegetation by species.

Ecological / site information:

- At each stratum sampled, the following site factors were measured or estimated:
  - elevation - soil texture - site history information
- At each plot the following were collected:
  - aspect (as an azimuth) - slope (%)
  - slash cover (%) - mineral soil exposure (%)
  - site series - duff thickness (average)

5.0 DATA ANALYSIS

Data from all 22 strata were analyzed using SAS (SAS Institute Inc. 1998).

Heights, diameters, and 5-year radial increments were analyzed as simple means. Because some plots did not contain trees of all species in all layers, per-hectare summaries were calculated using the total number of plots in that stratum as a divisor. Summary statistics of other site factors are shown in TABLE 3, and Appendix II.

Stump diameters were converted to dbh using a two-step method as described in Omule and Kozak (1989). Diameters from outside bark were converted to diameter inside bark, which were then corrected to dbh.

A correlation analysis on stratum means was conducted on independent variables in the data set against dependent variables (Appendix I). Independent variables were: elevation, number of years since harvest, duff thickness, shrub cover, estimated pre-harvest stocking, crown closure, post-harvest basal area/ha, and basal area of stumps (i.e., basal area removed). Dependent variables were: number of germinants/ha; 5-year radial increment; current leader growth of Layer 2, Layer 3, and Layer 4; and the number of post-harvest naturals/ha. Dependent variables were then modelled with a multiple linear regression, using all independent variables with Pearson correlation coefficients greater than 0.2. All possible combinations were tested, using Mallow's C_p statistic and adjusted r-square to select the best combination of independent variables.

In this report, examination of increment is confined to basal area increment; extrapolation to volume increment was not attempted. This approach was taken for a variety of reasons. Funding was insufficient to adequately sample the overstory layer using destructive sampling methods. Additionally, only a few tree heights and ages were measured. Although the authors recognize the omission of volumes in the study is a limitation, they felt that presenting volumes would be

both inaccurate and misleading given that data collection focussed on stand dynamics, regeneration, and growth rates.

6.0 RESULTS

6.1 Regeneration Establishment and Density

6.1.1 Seedbed

In all but two strata, germination occurred exclusively on mineral soil. In the other two strata, 85% and 93% of the seedlings germinated on mineral soil. Other minor amounts of germinants were found on rotted wood and moss mats.

6.1.2 Germinants

6.1.2.1 Density of Germinants

The numbers of germinants/ha were highly variable, ranging from 0 to 9091/ha, with an average of 3610/ha (TABLE 3). All but one stratum had at least 154 germinants/ha. The data do not show how many of these germinants will develop into Layer 4 individuals.

TABLE 3. Simple statistics summary, all strata.

Variable	Mean	Standard deviation	Minimum	Maximum
Trees (overstory)				
Basal area of stumps (m^2/ha)	15.6	3.9	6.7	22.7
Stumps (no. stems/ha)	478.0	246.3	125.0	1045.0
Residual basal area (m^2/ha)	13.7	4.2	8.4	27.6
Crown closure (%)	40.0	9.9	24.2	71.0
Vegetation				
Vegetation cover (shrubs & herbs only) (%)	80.4	8.5	50.8	90.0
Site variables				
Time since harvested (yr)	9.1	3.5	5.0	14.0
Duff depth (cm)	3.1	0.6	2.1	4.3
Elevation (m)	1007.0	43.7	910.0	1100.0
Mineral soil exposure (%)	7.0	2.6	5.0	14.4
Shrub cover (%)	79.9	9.9	50.8	95.0
Slash cover (%)	12.4	6.1	6.1	30.9
Slope (%)	9.9	5.7	0.0	25.0
Regeneration (advanced and natural)				
Residual stand (no. stems/ha)	2992.0	1457.0	1175.0	6450.0
Germinants (no./ha)	3610.0	3021.0	0.0	9091.0
5-yr increment (cm)	1.0	0.2	0.5	1.3
Leader height of Layer 2 (cm)	16.4	14.2	2.0	47.5
Leader height of Layer 3 (cm)	14.8	7.3	3.1	32.6
Leader height of Layer 4 (cm)	7.6	2.3	3.6	13.2
Naturals (no./ha)	2011.0	1391.0	188.9	5067.0

6.1.2.2 Effects of Overstory Species on Germinants

Most of the germinants (83%) were Douglas-fir. Douglas-fir was proportionally better represented in the Germinant Layer (83%) than in Layer 1 (63%). Lodgepole pine was also better represented in the Germinant Layer (9%) than in Layer 1 (7%). Both western larch and ponderosa pine were better represented in Layer 1 than as germinants (FIGURE 3).

6.1.2.3 Effects of Vegetation on Germinants

Vegetation species were sorted and grouped according to the moisture regime and compared with the frequency of germinant occurrence (FIGURE 4). No clear pattern emerged.

Although pinegrass is frequently considered to be a problem for regeneration in the IDF, the sites in this study did not seem to be affected, either positively or negatively, by pinegrass. This may be because most of the study stands did not have openings large enough (i.e., >1 tree length wide) to encourage pinegrass growth (Simard et al. 1997). Germinants were found in 56% of the plots containing pinegrass. However, the survey did not record species cover, so no conclusions can be made regarding the effect of pinegrass cover on germination.

Vegetation species indicative of moister microsites were more likely to have germinants associated with them. Greater than 80% of the plots containing either *Salix* spp. or *Acer glabrum* had one or more germinants within the plot. Many plants with a low growth habit (e.g., *Antennaria neglecta, Antennaria microphylla, Linnaea borealis,* or *Chimaphila umbellata*) were also frequently associated with conifer germinants. In particular, *Linnaea borealis* and *Chimaphila umbellata* were associated with germinants more than 80% of the time.

6.1.2.4 Effects of Site Factors on Germinants

Together, shrub cover, slash cover, and residual stems/ha accounted for 54% of the variation in germination count (Appendix I). That is, with increasing residual stems, or vegetation cover, or percent slash cover, numbers of germinants increased.

6.1.2.5 Effects of Residual Basal Area on Germinants

Correlation analysis (Appendix I) showed no correlation between basal area retained and numbers of germinants. Plotting germination density against residual basal area revealed no relationship between the two, nor was any threshold level evident (FIGURE 5).

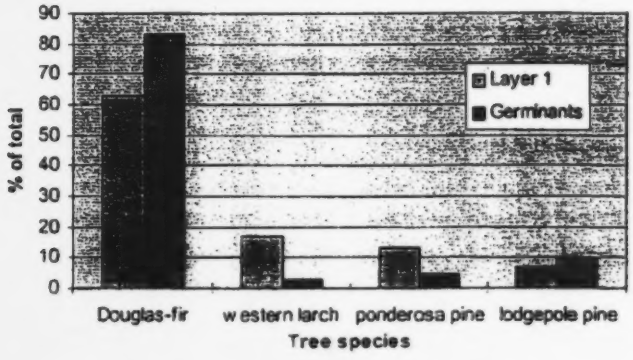

FIGURE 3. Composition of Layer 1 and Germinant Layer, by species.

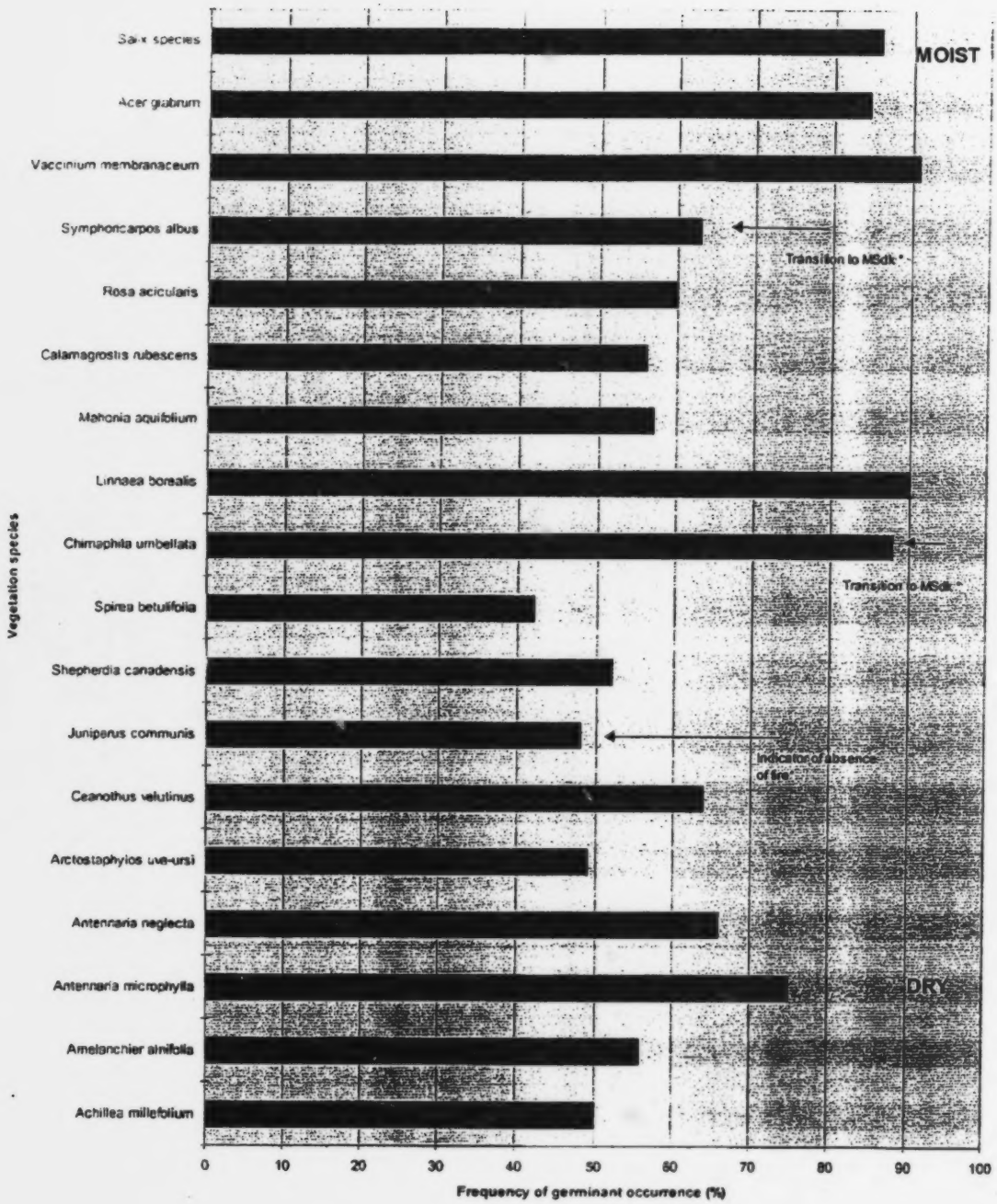

FIGURE 4. Germination frequency and ground vegetation.
A list of common names of plants appears in Appendix III.
MSdk = dry variant of the Montane Spruce biogeoclimatic zone.
(* Tom Braumandl, Research Ecologist, Nelson Forest Region, BCMOF; personal communication, 1998.)

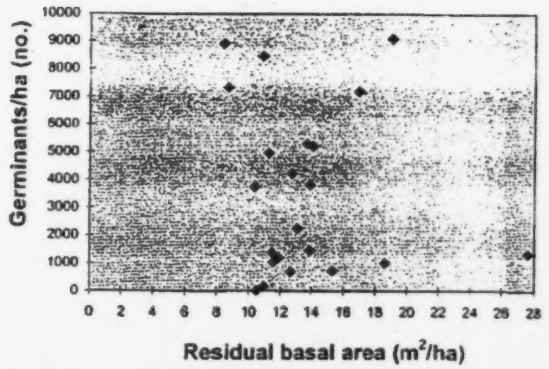

FIGURE 5. Germinants/ha, by residual basal area.

6.2 Stand Structure

6.2.1 Average Density in Layers 2, 3, and 4

Layer 4 trees comprised an average of 87% (3680) of the stems/ha. There were fewer trees/ha in Layer 3 (442 stems/ha, or 11%), and even fewer in Layer 2 (79 stems/ha, or 2%) (FIGURE 6).

6.2.2 Comparison of Stem Densities in Layers 2, 3, and 4

The ratio of the number of trees in successive diameter classes $(q)^2$ is typically used as a tool for managing all-aged stands. In this study, q was used to compare density of Layer 4 to Layer 3, and of Layer 3 to Layer 2 (TABLE 4 and FIGURE 7).

If the data from Unit 5, the four strata at Sand Creek, are excluded, the q values change significantly. The q value comparing Layer 3 to Layer 2, and Layer 4 to Layer 3, both change to about 10:1, and the standard deviation also drops below the average q value. Great variation in densities and stem distribution (clumpiness) produce large ranges in q, demonstrating that, at least in the lower layers, these stands do not represent the classic inverse "J" curve[3] used for managing uneven-aged[4] stands.

6.2.3 Height Growth of Layers 2, 3, and 4

Leader growth for all layers was generally comparable (FIGURE 8), except for the strata on two units at Lost Dog (Units 7 and 8). There are no apparent explanations for the better leader growth on those strata.

[2] q value. A multiplier that provides a stand diameter distribution with an increasing number of stems in smaller diameter classes. With higher q values, more small trees will be retained on site. With lower q values, more large trees will be retained on site. One tree of a maximum diameter class is used as the starting point (BCMOF 1992).

[3] Inverse-J curve. When the diameter distribution of total trees/ha is determined using the multiplier "q", and is plotted against diameter class, the resultant shape of the curve is that of an inverse-J (BCMOF 1992).

[4] Uneven-aged stand. A stand in which three or more distinct age classes occupy approximately equal areas and provide a balanced distribution of diameter classes. Age classes mean trees within a 20-year age increment up to age 140, then a single class for trees between the ages of 141 and 250 years, and then a single class for trees greater than 250 years of age (Province of BC 1995).

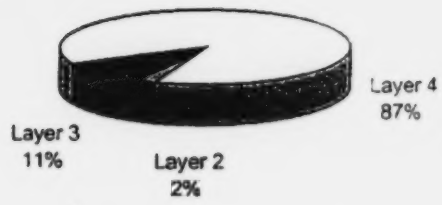

FIGURE 6. Composition of Layers 2, 3, and 4 (stems/ha).

TABLE 4. q values for Layers 3:2 and 4:3.

Layers	Average *q*	Minimum *q*	Maximum *q*	Standard deviation
3:2	6.5	1	21.4	5.6
4:3	15.6	2	59.5	18.9

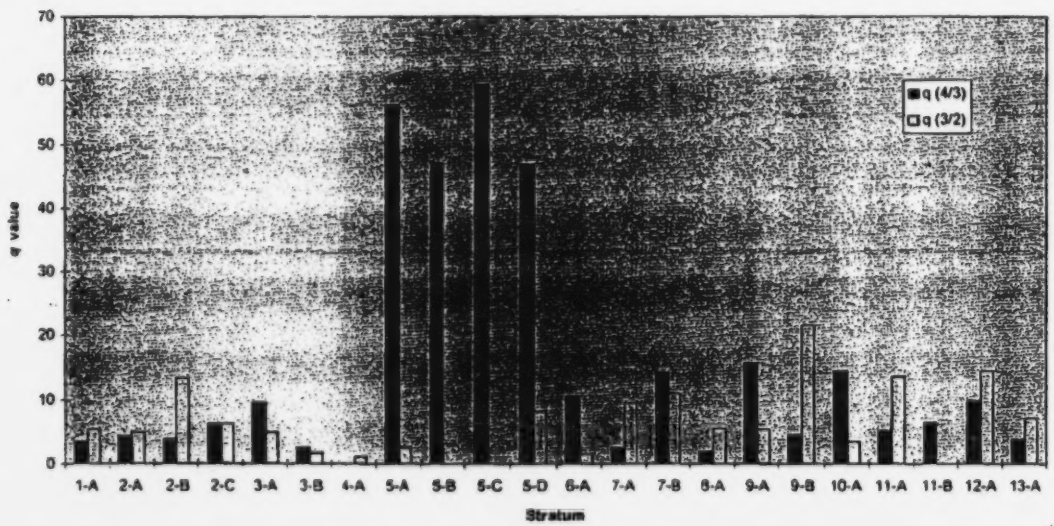

FIGURE 7. q values for Layers 3:2 and 4:3.

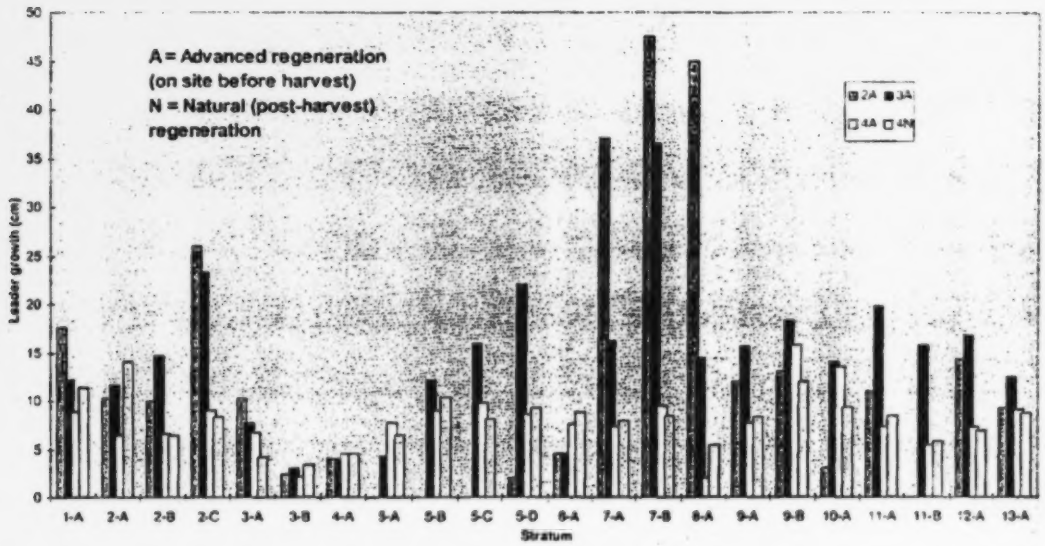
A = Advanced regeneration
(on site before harvest)
N = Natural (post-harvest)
regeneration
Leader growth (cm)
Stratum
1-A 2-A 2-B 2-C 3-A 3-B 4-A 5-A 5-B 5-C 5-D 6-A 7-A 7-B 8-A 9-A 9-B 10-A 11-A 11-B 12-A 13-A

FIGURE 8. Leader growth for Layers 2, 3, and 4, by strata.

6.2.4 Advanced and Post-Harvest Regeneration for Layers 2, 3, and 4

Layer 4 regeneration was abundant, ranging from 2011 to 5067 stems/ha. Generally, the stands in the study were well stocked. This trend appears consistent with other IDF biogeoclimatic zones in BC. Catton (1997) found a range of 3300 to over 16 000 stems/ha in the IDFdk3 and IDFxm of the Cariboo area.

All of Layer 2 consisted of advanced regeneration, while 92.7% of Layer 3 and 45.3% of Layer 4 were on site prior to harvest (FIGURE 9). Many of the Layer 4 trees were older than anticipated. This became apparent only when the trees were destructively sampled and aged. Identifying the origin of the trees in this study was difficult. The number of trees of post-harvest origin were likely over-estimated. Only a few stems were destructively sampled. More destructive sampling would be needed to confirm this observation.

Distribution of advanced regeneration was sporadic, occurring primarily in small dense thickets which were undisturbed by harvesting activity. This is consistent with other studies (Seidel and Head 1983; Marshall and Wang 1996). The post-harvest naturals (Layer 4 stems) were better distributed, with a lesser tendency to be clumped.

Although Williamson (1973) found that stocking density increased with the length of time after harvesting, this was not the case in this study. No relationship could be detected between time since harvest and stocking level. This may be a result of the relatively short harvesting time span (1982-1992) assessed in this report, or it may be indicative of the fact that regeneration occurs more slowly in the IDF subzone. The lack of a relationship might also be a reflection of the great variability in density in stands in the IDF.

6.2.5 Species Composition of Regeneration and Post-Harvest Overstory

In the overstory (Layer 1), Douglas-fir was the lead species with 63% of the stems. Western larch comprised 17%, ponderosa pine 13%, and lodgepole pine 7%. Trembling aspen, paper birch, and spruce together made up less than 1% of the overstory.

The species composition of the understory (Layers 2, 3, and 4) closely reflected the composition of the post-harvest overstory, ±3% (FIGURE 10). Douglas-fir was the leading species at 66%. Western larch totalled 15%, ponderosa pine 11%, and lodgepole pine 7%. Trembling aspen, paper birch, and spruce together comprised <1% of the understory.

It is likely that the lodgepole pine stems in Layers 2, 3, and 4 are of the same cohort as the Layer 1 lodgepole pine that were harvested. This would mean that these stems were not part of post-harvest natural regeneration. To determine whether they were of pre- or post-harvest origin would have required destructive sampling. This was not done.

Given their regeneration strategies, the Douglas-fir, western larch, and ponderosa pine in Layers 2, 3, and 4 likely represent several cohorts, of both pre- and post-harvest origin.

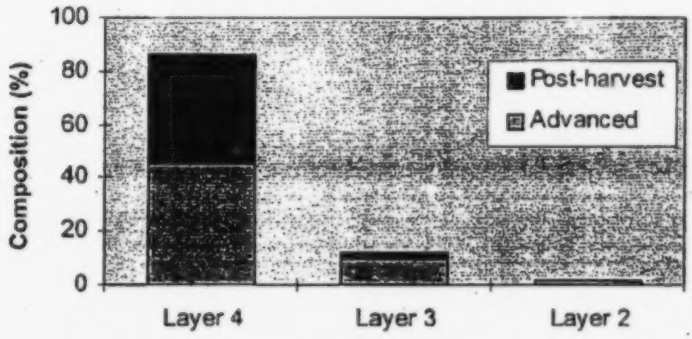

FIGURE 9. Advanced and post-harvest regeneration for Layers 2, 3, and 4.

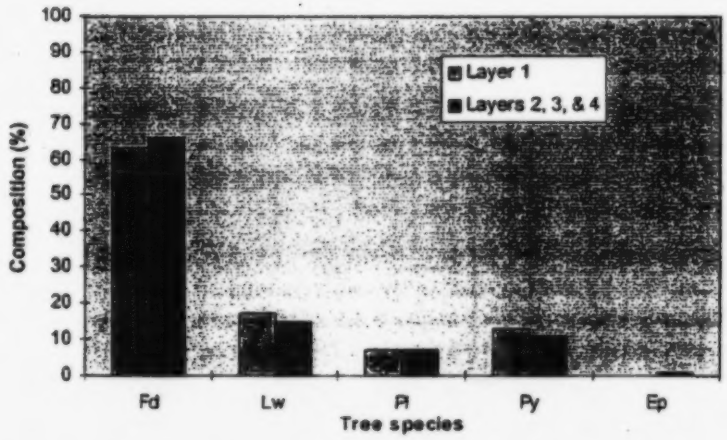

FIGURE 10. Species composition of the overstory (Layer 1), and understory (Layers 2, 3, and 4).

6.3 Effects of Harvesting

6.3.1 Residual Basal Area

The pre-harvest basal area in the study stands averaged 29.3 m^2/ha (range 21.0 to 34.8). This value compares well to the basal area in permanent sample plots in the IDFdm2 of 27.3 m^2/ha (range 11.8 to 46.2)[5]. Those data show that the study stands were representative of the rest of the IDFdm2.

Harvesting removed between 13 and 70% of the original basal area. Most stumps were in either the 18.5-cm or 28.5-cm diameter classes. A few stumps had larger diameters. Almost half of the basal area removed in the study stands was lodgepole pine (47%); Douglas-fir accounted for 34%, western larch 13%, and ponderosa pine 6% (FIGURE 11).

Average basal area removed was 15.6 m^2/ha (range 6.7 to 22.7), with an average of 13.7 m^2/ha (range 8.4 to 27.6) remaining after harvest.

In contrast, nearly half the stems removed were Douglas-fir (54%). Lodgepole pine accounted for 32%, western larch 13%, and ponderosa pine 1% (FIGURE 12).

6.3.2 Diameter Distribution of Residuals

Because many larger stems and few smaller stems were harvested, the majority of the post-harvest stocking exists in the diameter classes smaller than 10 cm (FIGURE 13).

6.3.3 Blowdown

Blowdown was rare, generally ranging from 0 to 5.2% of the post-harvest Layer 1 trees. At one location (Unit 7) blowdown comprised 10.7% of the 28 trees in Layer 1. Most of the blowdown was in the 18.5-cm diameter class, but trees up to 58.5 cm dbh blew down. Seidel and Head (1983) and Williamson (1973) both found minimal blowdown in similar stand types.

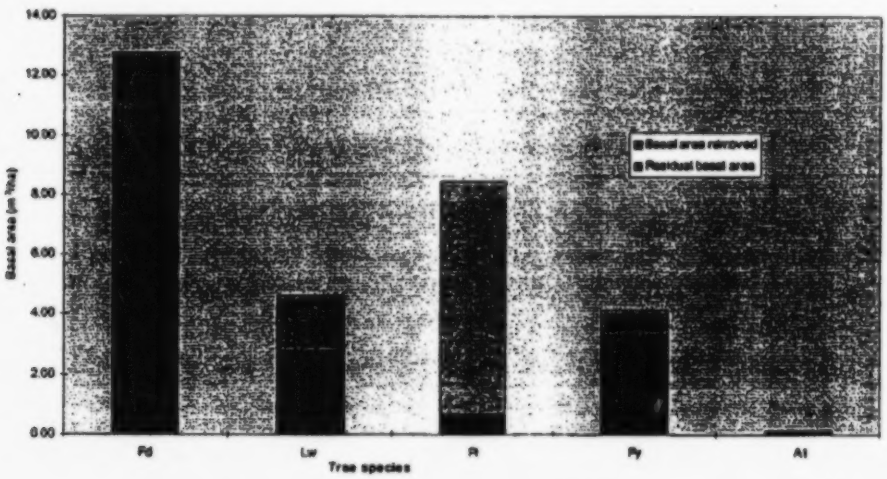

FIGURE 11. Residual and harvested basal areas, by species.

[5] B. Snowden, Silviculture Decision Support Specialist, BCMOF, Victoria; personal communication, 1998.

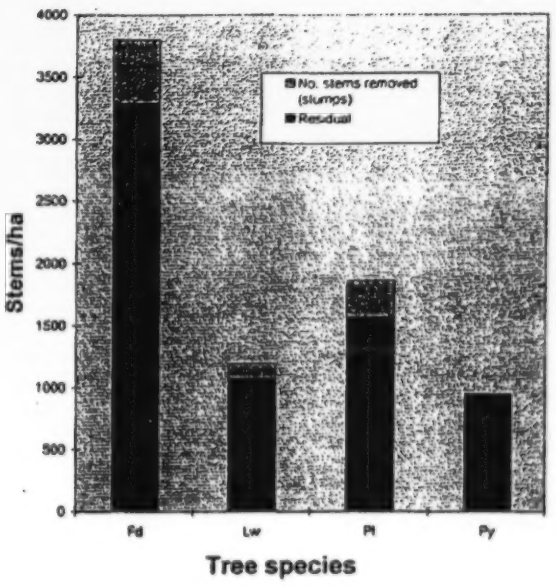

FIGURE 12. Number of residual and harvested stems/ha, by species.

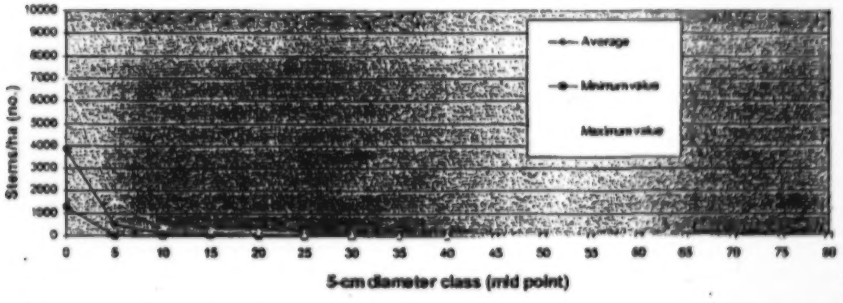

FIGURE 13. Residual stand: minimum, maximum, and average stems/ha, by 5-cm diameter class. (There are no trees in the 70- and 75-cm diameter classes.)

6.4 Post-Harvest Increments

6.4.1 Annual Radial Increments

The annual basal area increment/ha averaged 0.31 m^2/ha, and ranged from 0.21 to 0.49 m^2/ha (FIGURE 14). No obvious differences existed in radial growth by species or by diameter class. Most of the strata at Sand Creek (Strata 4A, 5B, 5C, and 5D), as well as one stratum at Lost Dog (7A), showed the slowest increment. While it is unclear why the stratum at Lost Dog was growing slowly, most of the Sand Creek strata had more than 10% visible, above-ground

Armillaria indicators. It is possible that the *Armillaria* is reducing the growth of residual Layer 1 and Layer 2 trees.[6]

6.4.2 Basal Area Increment and Basal Area/Ha

While poorly correlated, generally, annual basal area increment appeared positively correlated with residual basal area (FIGURE 15). As residual basal area was reduced, basal area increment decreased. With one exception (Stratum 10A), all strata with residual basal areas <11.5 m^2/ha had basal area increments <0.31m^2/ha/yr. Conversely, with three exceptions, Strata 2C, 4A, and 5B, all strata with residual basal areas >12 m^2/ha had basal area increments >0.31m^2/ha/yr.

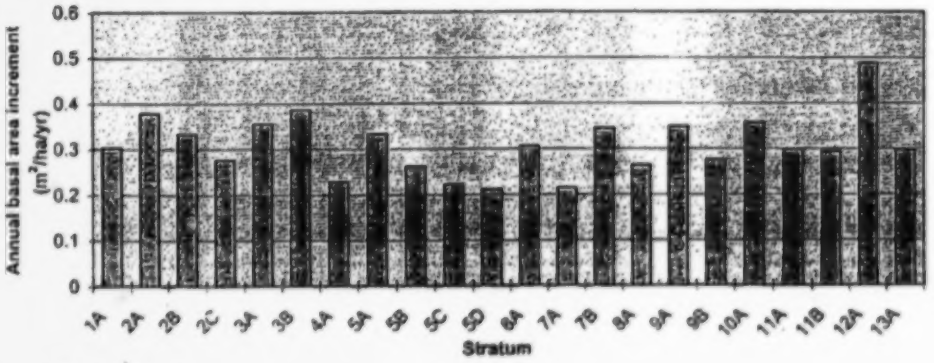

FIGURE 14. Annual radial increment/ha, by stratum.

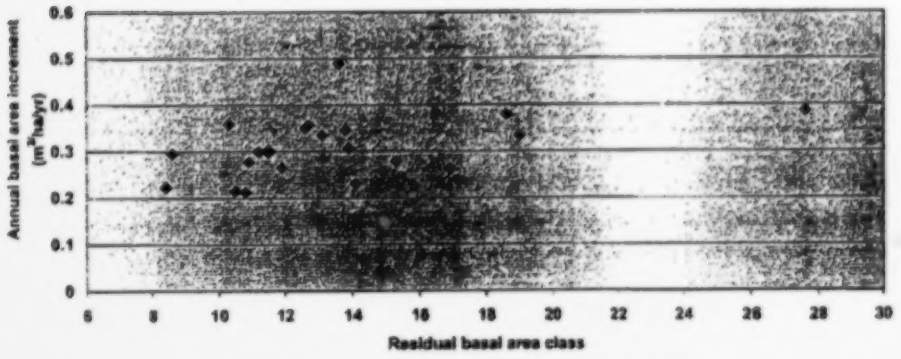

FIGURE 15. Annual increment, by residual basal area class.

[6] D. Norris. Pathologist. Nelson Forest Region, BCMOF; personal communication, 1998

7.0 DISCUSSION OF STUDY RESULTS, AND MANAGEMENT IMPLICATIONS

The study sites represent a snapshot in time for a 10-year period of harvesting (1982-92) in the Cranbrook and Invermere Forest Districts. During that time, harvesting emphasized salvaging stands infested by mountain pine beetle.[7] Trends demonstrated in this study may not apply to current forest management practices because of the following factors:

- The Forest Practices Code has since come into effect, with associated limitations on forest-floor displacement and soil disturbance (BCMOF and BCMOE 1995; Province of BC 1995).
- The *Kootenay Boundary Land Use Plan Implementation Strategy* (BCMOF 1997b) calls for lower stocking standards on the IDFdm2-03.
- Current forest practices emphasize burning for ecosystem restoration, to alter the species, structure, density, and understory vegetation in the stand.

7.1 Factors Affecting Germination

7.1.1 Effects of Seedbed

Although rotted wood can be a suitable seedbed,[8] most germinants in this study were found on mineral soil. In the IDF, rotted wood tends to dry out rapidly in the open stands created by harvesting. This possibly accounts for its lack of effectiveness as a seedbed in this study. In contrast, mineral soil tends to dry out less rapidly. Williamson (1973) and Minore (1979) both confirm the importance of site preparation and mineral soil exposure for encouraging regeneration in Douglas-fir types.

This study was not designed to establish how many of the germinants in this survey will be recruited to Layer 4. However, the presence of post-harvest trees in Layer 4 shows that germination and recruitment have been successful since harvest.

Current stand conditions do not represent the same site and stand conditions that existed immediately following harvest. Germination and recruitment were probably most successful in the period immediately following harvest when more mineral soil was exposed. Since then, vegetation, in-fill, and snow compaction would have reduced the receptivity and abundance of the mineral soil seedbed.

The severity of the summer climate in the IDF likely results in high seasonal germinant mortality. However, more germinants will survive in some (less severe) summers than in others. A detailed destructive analysis of Layer 4 trees and longer term monitoring of germinant survival are necessary to better qualify the recruitment pattern into Layer 4.

The Forest Practices Code (BCMOF and BCMOE 1995) now limits forest floor disturbance caused by timber-harvesting activities. These limitations may have significant effects on current prescriptions that rely on natural regeneration by reducing the amount of mineral soil exposure permissible, and thus limiting the available seedbed.

7.1.2 Effects of Overstory

Western larch and ponderosa pine regeneration are less well represented than the overstory composition would suggest. Douglas-fir is better represented. This shift in species composition likely occurred because Douglas-fir is more shade tolerant, and because the existing seedbeds

[7] E. Begin, Forest Health Officer, Invermere Forest District, BCMOF, personal communication, 1998.

[8] A. Vyse, Research Forester, Kamloops Forest Region, BCMOF; personal communication, 1998.

were more favourable to Douglas-fir than either western larch or ponderosa pine. Both ponderosa pine and western larch require sunnier and more disturbed conditions than are usually provided by harvesting alone (Burns and Honkala 1990). The shade tolerance of Douglas-fir (Minore 1979) also favours its persistence in the understory.

7.1.3 Effects of Vegetation

The data do not show whether the shrub species are acting as shade in the absence of a conifer overstory, or if shrub presence is being controlled by the overstory. Vegetation may help elevate humidity and thus reduce transpiration stress in newly germinated seedlings, but it does so at the cost of reducing available soil moisture. Thus a conflict exists between moisture demands and the benefits of shade and increased humidity. Minore (1979) found that Douglas-fir seedlings were more responsive to higher levels of moisture and humidity than ponderosa pine seedlings. Low-growing vegetation may help to retain moisture and humidity and increase the probability of Douglas-fir germination compared to ponderosa pine. It is unclear from the data whether this relationship is occurring on the study sites. An alternative explanation is that species like *Salix spp.* are acting as indicators of more favourable moisture and the regeneration is responding to greater moisture availability on the site. This is likely the case. In contrast, *Arctostaphylos* is often associated with frost-prone areas and cold area channels (Steele and Geier-Hayes 1993). In this study, *Arctostaphylos* was one of the least likely species to be associated with conifer germinants.

7.1.4 Effects of Site Factors

Correlation analysis showed that the number of residual stems, vegetation cover, and percent slash cover accounted for 54% of the variation in numbers of germinants. These factors are likely working synergistically to increase the likelihood of germination success. For example, high vegetation cover in the absence of a conifer overstory would not lead to significant amounts of germinants; but, the interactions between these variables enhances the probability of germinant success. Seidel and Head (1983) also found that greater stocking was generally associated with increasing density of the overstory. It is also possible that vegetation cover is both directly and indirectly influencing germination success. Vegetation cover may also be an indirect expression of increased availability of soil moisture, which in turn is increasing the probability of germinant survival.

7.1.5 Effects of Residual Basal Area

This study was unable to detect any relationship between residual basal area and germination success. However, other studies did not find a strong correlation between residual basal area and germinants either (Williamson 1973; McDonald 1976; Minore and Carkin 1978; Graham et al. 1982; Seidel and Head 1983; Siedel 1983; Day 1996b; Marshall and Wang 1996; Catton 1997). Germination depends less on basal area than on other factors such as seed supply and seedbed conditions (e.g., shade and moisture). Basal area has only an indirect effect on these parameters. It appears that there are too many confounding factors to permit a straightforward interpretation of the relationship. In this study, the lack of correlation may be partially attributed to the narrow range of residual basal areas in the stands selected.

The relative abundance of Douglas-fir regeneration compared to that of other species is likely due to several factors:

- Lack of fire. Ponderosa pine is more fire resistant; therefore, without fire it has no competitive advantage over Douglas-fir. Lodgepole pine regeneration is primarily fire dependent; without fire, its regeneration success is reduced compared to Douglas-fir.

- Douglas-fir is more shade tolerant than either of the pine species or larch, and therefore it regenerates better in these partially shaded environments.
- Douglas-fir is less drought tolerant than ponderosa pine, causing more stressed Douglas-fir that will produce more frequent cone crops (stress crops) than ponderosa pine.
- Ponderosa pine and western larch require a more scarified mineral soil seedbed than Douglas-fir (Minore 1979).
- There are more Douglas-fir than ponderosa pine in the residual stand, such that the Douglas-fir may produce more seed.

Without intervention, Douglas-fir will continue to regenerate better than other species. With limited mineral soil exposure, there will be less regeneration; any regeneration that does establish tends to occur in small dense thickets. Without mid-rotation fire, Douglas-fir will continue to be more abundant than ponderosa pine. Although shading and competition generally inhibit germination and survival of lodgepole pine, in some areas it is capable of establishing itself in the shade of lightly cut stands; hence, lodgepole pine may persist in the understory. However, in the absence of fire, lodgepole pine will eventually be succeeded by the more shade-tolerant and longer lived Douglas-fir (Burns and Honkala 1990).

7.2 Advanced and Post-Harvest Regeneration in Layers 2, 3, and 4

Studies similar to this one found that components of both natural and advanced regeneration made important contributions to future stocking (Seidel and Head 1983; Seidel 1983). They showed that the largest single components of the regeneration are natural post-harvest seedlings, three years and older, and the majority of the seedlings (57%) became established after harvesting. Further, they found that although advanced regeneration was important, it comprised only about one-fifth of the total amount of regeneration. Thus, the proportion of advanced versus post-harvest natural regeneration was the opposite of the findings in this study. These results may change with time.

7.3 Shift in Species Composition

In this study, 82.9% of the germinants were Douglas-fir (Figure 3). Douglas-fir was also the leading species in Layers 3 and 4. It appears that a species shift is occurring at the time of germination. The availability of seed does not appear to be a limiting factor for Douglas-fir, while both the seedbed and the seed source may be limiting factors for ponderosa pine and larch (Minore 1979). Arno et al. (1995) found that ponderosa pine often occurred in seral stands, and that underburns prevented the establishment of more-shade-tolerant competitors such as Douglas-fir, thus resulting in a greater proportion of ponderosa pine in climax stands. If underburns or wild fires are controlled, surface fuels and conifer thickets increase. Arno et al. (1995) also found that on both dry and moist sites, the major changes in stand structure involved: i) an increase in basal area and in number of trees/ha, and ii) the development of an understory of shade-tolerant trees, in this instance, Douglas-fir instead of ponderosa pine. Consequently, Douglas-fir comprised the majority of the understory trees in the study by Arno et al. (1995). This was also the case in this study, and probably for the same reasons.

Lodgepole pine has a complex fire response depending on environmental conditions and the extent of competition from associated species. Although individual trees of this thin-barked species are usually killed by fire, the species is well adapted to regenerate after a hot fire. Within the IDFdm2, many fires occurred during the early 1900s, culminating with several large fires

during the drought of the 1930s. Then, in the 1940s, organized fire suppression started. This chronology allowed the initiation and maintenance of lodgepole pine as a minor seral species in these stands. Given the density of the Douglas-fir understory and the paucity of lodgepole pine in the regeneration layer, lodgepole pine will not likely repeat this role.

In similar stands but in slightly different ecosystems in the United States, Arno et al. (1995) reported similar trends from the 1900s to the present. Basal areas changed dramatically over 90 years, with an average increase of 13.6 m^2/ha (range 0.7 to 32.3 m^2/ha) largely due to the development of dense thickets of Douglas-fir. Arno et al. (1995) also reported a decrease in the percentage of ponderosa pine, and as much as a tenfold increase in the percentage of Douglas-fir.

With the exception of the lodgepole pine, these changes in stand structure parallel the trends that have occurred in the IDFdm2 study stands. Selective harvesting of ponderosa pine for use as doors and windows during the early 1900s further reduced the density of ponderosa pine in the study stands. Evidence of this early harvesting was found throughout the study stands, but was not assessed; the large stumps were either rotten and crumbling, or covered in moss.

While the current stocking standards (Silviculture Interpretations Working Group 1993) generally recommend Douglas-fir, ponderosa pine, lodgepole pine, and/or western larch, depending on the site series, these stands are generally developing into Douglas-fir-dominated stands.

7.4 Future Harvesting Options

7.4.1 Silviculture System

Although all-aged management is frequently considered for stands in the IDF, and stand structure often permits that strategy, recent selective harvesting has made this a difficult option in the study stands.

Historically, the pre-harvest study stands were deficient in the smaller diameter classes of Layer 1 and the larger diameter classes of Layer 2. The harvesting that took place from 1982 to 1992 exaggerated that deficiency by selecting for lodgepole pine. The post-harvest stand structure of the study stands (FIGURE 13 and Appendix II-10) shows a surplus of growing stock in the diameter classes smaller than 10 cm, and few trees in Layer 1. The resultant stand structures resemble even-aged stands more than the reverse "J" curve expected for an all-aged stands. Therefore, during the current rotation, it would be difficult to manage these sites as all-aged stands.

Several management objectives are possible for these stands. The desired structural and spatial characteristics of the stand will differ for each objective. For example, managing for ungulate habitat might mean retaining more trees in Layers 2 and 3 in thickets for thermal and hiding cover. In contrast, managing for timber production would place greater emphasis on more uniform stem distribution to maximize volume increment on the better stems. Managing to establish an open, old-growth, Douglas-fir forest would require a different target stand structure, possibly including the re-introduction of fire.

Cattle grazing is common in these stands. To optimize range use, another target stand structure would be specified, probably with a lower target stocking (BCMOF 1997b) and few thickets. However, the optimal structure for one use may not be fully compatible with that of another use.

It is beyond the scope of this report to discuss in detail the strategies for optimizing each management objective. Moreover, for each management objective that is adopted, the strategy for achieving that objective should probably be based on the assumption that these stands most closely resemble young, irregularly spaced, even-aged stands. Although, in some cases there are a few large trees (Layers 1 and 2) that may help achieve certain stand structure objectives.

7.4.2 Harvest Scheduling

The length of time a stand takes to return to its pre-harvest basal area is a convenient measure of the ability of a stand to respond after harvesting. That ability to respond is affected by several factors, none of which controlled in this study:

- Level of growing stock left after harvest.
- Spatial distribution of that growing stock.
- Distribution of that growing stock through the diameter classes.
- Tree species and their silvicultural characteristics.
- Stand health.
- Site quality.

The extent to which each of these factors affects growth depends on the management objectives.

Recent harvesting in the study stands removed between 13 and 70% of the pre-harvest basal area. At their respective present growth rates , the study stands will take from 11 to 90 years to return to their respective pre-harvest basal areas (FIGURES 16 and 17). Similarly, Catton (1997) found that in the IDF subzones of the Cariboo Forest Region harvesting removed 14-89% of the pre-harvest basal area. Catton's calculations showed that those areas would take between 5 and 131 years to recover to their respective pre-harvest basal areas.

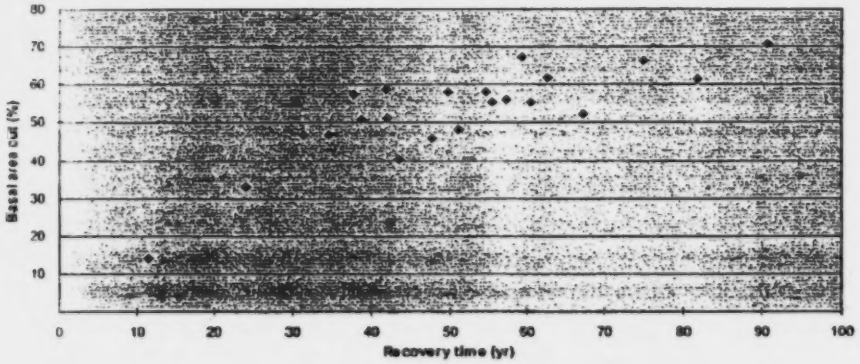

FIGURE 16. Time required for the stand to recover its pre-harvest basal area, by percent basal area cut.

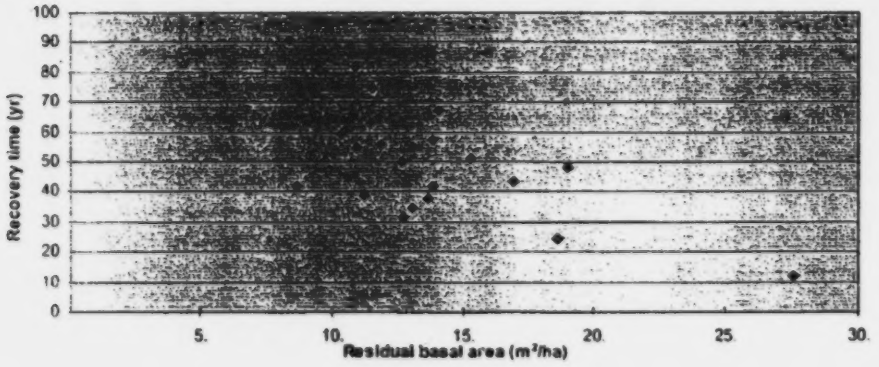

FIGURE 17. Time required for the stand to recover its pre-harvest basal area, by residual basal area.

Optimum stocking in the study stands probably occurs below pre-harvest basal area, and the data from this study suggest that incomplete site occupancy may start to occur below about 12 m^2/ha.

To use one example, if these study stands are to be managed to 17 m^2/ha as Day (1997b) recommends for the IDF in the Cariboo, at the present basal area increment the average stand in this study will reach that value in approximately 13 years. Another 30 years will be required before 10 m^2/ha can be harvested without reducing the residual stocking below 17 m^2/ha. We assumed that all the growth would be on Layer 1 and 2 trees. In reality, much of that growth would be on smaller trees. This example also assumes that the immediate post-harvest growth can be maintained in a stand with irregular stem distribution and with no renewed expression of *Armillaria* root disease. Both are unlikely. The authors expect that this will lead to reduced growth rates and a longer period before a portion of these stands can be harvested again.

7.5 Forest Health

Considerable debate exists over the current health of IDFdm2 stands relative to their historical health (Arno et al. 1995). Unfortunately, the survey method used in this study proved inadequate for drawing specific conclusions regarding the level of *Armillaria* believed to be present.

According to the Armillaria Risk Assessment Matrix (Norris et al. 1998), most of the strata in this study had a moderate (20-25) risk of incurring Armillaria. In this study, the surveyors recorded only infected trees using above-ground indicators. They did not look for confirming disease signs such as *Armillaria* mycelial fans or rhizomorphs. Using this technique, very little *Armillaria* was noted in most of the strata. The exceptions to this were the strata at Sand Creek (Cranbrook Forest District) where more than 10% *Armillaria* infection was recorded. However, Norris[9] notes that in the IDF, even if no above-ground symptoms are observable, an average below-ground infection rate of 10%, is likely. Even though *Armillaria* was not reported in other study units, it may be the cause of the lower radial increments at units such as Lost Dog (Units 7, 8, and 9).

Arno et al. (1995) states that in fire-excluded stands similar to the IDFdm2, "tree health is so poor that major mortality will probably occur regardless of treatment in the short term". Norris and Begin[10] note that the overall health of the IDFdm2 may have been compounded by previous harvesting practices. With the removal of the lodgepole pine, the stumps likely supplied an abundant food source for *Armillaria*. The *Armillaria* has now become an active component of the IDFdm2.

The resurgence of *Armillaria* may result in lowered radial growth. Radial increment varied considerably between strata. Sand Creek, where *Armillaria* was identified by the presence of above-ground symptoms, had some of the lowest radial increments in the study (FIGURE 14). This may be a direct response to the *Armillaria*; if this is the case, reduced radial increment is expected in other strata.

With lower radial increments, the study stands will take correspondingly longer to recover to their pre-harvest basal areas. Norris and Begin[11] estimate this may take as much as an additional 30 to 40 years.

[9] Norris. See Footnote 6.

[10] Norris and Begin. See Footnotes 6 and 7.

[11] Norris and Begin. See Footnotes 6 and 7.

8.0 CONCLUSIONS

In 1998, the Forest Sciences Section of the Nelson Forest Region (BC Ministry of Forests), initiated a retrospective evaluation of natural regeneration and stand dynamics in partially cut stands in the Kootenay variant of the Interior Douglas-Fir Dry mild biogeoclimatic subzone (IDFdm2) (Braumandl and Curran 1992). The results from the study were intended to assist foresters in preparing future prescriptions that include partial cutting. The study focussed on IDFdm2 stands in the Nelson Forest Region that were partially cut between 1982 and 1992.

The main conclusions of the study are:

- Post-harvest natural regeneration, although variable, was generally successful. In some strata regeneration was low (178 stem/ha), but on other strata it was plentiful (5000 stems/ha).
- The understory species composition reflects the overstory tree species composition within ±3%. These stands now consist almost exclusively of Douglas-fir, with minor components of ponderosa pine, lodgepole pine, and larch, in the understory.
- There was no correlation between residual basal area and numbers of germinants. However, together, shrub cover, slash cover, and residual stems/ha accounted for 54% of the variation in germination count.
- The study stands are most representative of an irregular shelterwood consisting primarily of small (Layers 3 and 4), irregularly distributed Douglas-fir. Currently, the stands cannot be defined as multi-layered, particularly because a gap exists in the growing stock of Layers 2 and 3. This gap is partially due to the historical patterns of regeneration establishment, but the gap has been further compounded by harvesting many of the small-diameter stems in Layers 1 and 2.
- Most of the basal area harvested was lodgepole pine (47%) in the 18.5-cm and 28.5-cm diameter classes. This is consistent with the lodgepole pine salvage prescriptions of the time.
- Current growth rates are slow, with mean basal area increments of 0.3 m^2/ha/yr (range, 0.21 to 0.49 m^2/ha/yr).
- If the study stands continue to grow at their current rates, individual strata will take from 11 to 90 years to return to their respective pre-harvest basal areas. At least 40 years must pass before the average stand in this study could again be harvested.
- Incomplete site occupancy is believed to occur below about 12 m^2/ha.

9.0 RECOMMENDATIONS

1. If the study stands are managed primarily for timber production, then the gap in the growing stock needs evaluation. Trees in Layers 3 and 4 should be spaced to permit faster recruitment of trees into Layers 1 and 2.
2. Results from this study suggest that residual basal areas should not fall below about 12.5m^2/ha on zonal sites in the IDFdm2 if timber production is the primary management objective. However, pending further evidence, that figure should be used only as a guideline.

   The reader is advised that other basal areas are recommended in the literature:

- To manage for mule deer winter habitat in the Cariboo Forest Region, Day (1997a) recommends residual basal areas of >17.5 m^2/ha on stems >7.4 cm dbh, over a 20-year cutting cycle.
- To establish open, old-growth, Douglas-fir / ponderosa pine forests in western Montana, Arno et al. (1995) recommend residual basal areas of 9-13.8 m^2/ha.
- The *Correlated Guidelines for Management of Uneven-Aged Drybelt Douglas-Fir Stands in BC* (BCMOF 1992) suggest that residual basal areas should be 15-25 m^2/ha.

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APPENDIX I. Correlation Analysis [a]

Variable [a]	Germinants/ha	5-yr radial increment (cm)	Leader height of Layer 2 (cm)	Leader height of Layer 3 (cm)	Leader height of Layer 4 (cm)	Stems/ha
Basal area of stumps	0.11198 22	0.34578 22	-0.08034 18	0.08728 22	0.47902 22	0.06696 22
Basal area of remaining trees	-0.14246 22	-0.53248 22	-0.19397 18	-0.44129 22	-0.34109 22	-0.32215 22
Crown closure in % of residual overstory	-0.00015 22	-0.20656 22	-0.05612 18	-0.15183 22	-0.51157 22	-0.02891 22
Vegetation cover, in %	0.48665 22	0.34098 22	0.0554 18	0.42006 22	0.33297 22	0.26363 22
Duff depth	-0.18505 22	0.05015 22	0.10567 18	0.0757 22	0.27065 22	0.2078 22
Elevation	-0.13435 22	0.63595 22	0.33443 18	0.4957 22	0.16425 22	0.15131 22
% mineral soil exposure	-0.34002 22	0.15267 22	0.70706 18	0.52685 22	0.18445 22	0.31069 22
Moisture regime	0.11819 22	0.00818 22	-0.07941 18	-0.02317 22	-0.26512 22	0.02472 22
% shrub cover	0.55254 22	0.23849 22	-0.23386 18	0.03392 22	0.18382 22	-0.04983 22
% slash cover	0.37489 22	-0.19018 22	-0.03181 18	-0.11713 22	0.01091 22	0.09574 22
% slope	-0.12746 22	-0.17908 22	0.08533 18	0.0336 22	-0.31864 22	-0.07966 22
Stems/ha of residual stand	0.53614 22	-0.07669 22	-0.10155 18	-0.11722 22	-0.40872 22	-0.14392 22
No. stumps/ha	0.41888 22	-0.02685 22	-0.42366 18	-0.20608 22	0.42616 22	-0.01459 22
No. years since harvest	-0.22564 22	0.01262 22	0.28012 18	0.18276 22	-0.52538 22	-0.03257 22
Adjusted r^2 / significant variables	0.545 % shrub cover. % slash cover. Stems/ha of residual stand.	0.44 Basal area of stumps. Elevation. 0.44 Basal area of remaining trees. Elevation.	0.46 % mineral soil exposure. 0.46 % mineral soil exposure. No. stumps/ha. 0.46 Elevation. % mineral soil exposure.	0.49 Vegetation cover in %. Elevation. % mineral soil exposure.	0.42 Crown closure in % of residual overstory. Stems/ha of residual stand. No. years since harvest.	

[a] For each variable, the r^2 value is given in the first line, and the number of strata on which the r^2 value was calculated is given in the second line.

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APPENDIX II. Tables of Information

Table II-1. Site parameters.

Stratum	Elevation (m)	Aspect (azimuth in degrees)	Years since harvest	Average vegetation cover (%)	Average vegetation height (cm)	Average slash cover (%)	Average crown closure (%)
1-A	1018	22	9	77.78	25	9.17	32
2-A	980	165	10	72.94	27	14.33	45
2-B	1000	118	10	82.81	29	7.62	49
2-C	1000	91	10	78.89	33	14.80	37
3-A	980	29	13	83.33	25	6.43	53
3-B	967	85	13	50.83	13	10.00	79
4-A	910	18	6	81.00	28	12.22	42
5-A	975	63	5	85.45	31	14.00	49
5-B	975	71	5	89.38	30	11.56	34
5-C	975	18	5	81.25	33	32.92	31
5-D	975	103	5	90.00	37	20.77	35
6-A	1040	67	5	68.75	20	22.31	39
7-A	1040	167	12	73.89	31	3.86	24
7-B	1020	167	12	81.67	28	9.38	52
8-A	1020	65	11	78.50	21	17.50	45
9-A	1014	80	6	84.38	28	7.31	48
9-B	1014	212	6	82.69	24	11.54	32
10-A	975	23	6	86.25	40	8.50	38
11-A	1100	120	14	87.50	32	10.50	45
11-B	1100	121	14	87.22	38	6.88	48
12-A	1050	51	12	82.06	25	15.71	45
13-A	1031	162	5	79.44	24	13.75	37

Table II-2. Germinants, by aspect and species.

Species	Aspect (in degrees)			% of total germinants
	Cool 315-7° (%)	Warm 147-270° (%)	Neutral 78-145° and 271-314° (%)	
Douglas-fir	18.05	23.90	40.98	82.93
Lodgepole pine	2.93	2.93	3.41	9.27
Ponderosa pine	2.44	0.49	1.46	4.39
Western larch	0.98	0.98	0.98	2.93
Spruce	0.49	0.00	0.00	0.49
Total	24.89	28.30	46.83	100.01

Table II-3. Germinant seedbed preference.

Stratum	Mineral soil (%)	Rotted wood (%)	Moss (%)
1-A	100	0	0
2-A	100	0	0
2-B	100	0	0
2-C	100	0	0
3-A	100	0	0
3-B	100	0	0
4-A	100	0	0
5-A	100	0	0
5-B	93.33	6.67	0
5-C	100	0	0
5-D	100	0	0
6-A	100	0	0
7-A	100	0	0
8-A	100	0	0
9-A	100	0	0
9-B	100	0	0
10-A	100	0	0
11-A	85.71	0	14.29
11-B	100	0	0
12-A	100	0	0
13-A	100	0	0

Table II-4. Frequency of germination, by vegetation frequency; sorted by moisture regime.

Vegetation species [a]	Frequency of germinants
Achillea millefolium	50
Amelanchier alnifolia	56
Antennaria microphylla	75
Antennaria neglecta	66
Arctostophylos uva-ursi	49
Ceanothus velutinus	64
Juniperus communis	48
Shepherdia canadensis	52
Spiraea betulifoli	42
Chimaphila umbellata	88
Linnaea borealis	90
Mahonia aquifolium	57
Calamagrostis rubescens	56
Rosa acicularis	60
Symphoricarpos albus	63
Vaccinium membranaceum	91
Acer glabrum	85
Salix species	86

[a] See Appendix III for the common names of plants.

Table II-5. Distribution of blowdown. [a]

Stratum	Species	Count of blowdown by diameter class (dbh in cm) Class midpoint 18.5 cm	28.5 cm	38.5 cm	48.5 cm	58.5 cm	Total stems in Layer 1	% blowdown by stratum
1-A	Fd	1				1		
	Pl	1						
							97	2.06
2-A							76	0.00
2-B							135	0.00
2-C							63	0.00
3-A							54	0.00
3-B	Pl	2					75	2.67
4-A	Fd	1					51	1.96
5-A	Fd		1					
	Pl	1						
							130	1.54
5-B	Fd			1			71	1.41
5-C	Fd	1					40	2.50
5-D							58	0.00
6-A	Fd			1			99	1.01
7-A	Py	2	1				28	10.71
8-A							48	0.00
9-A							84	0.00
9-B	Py	1					50	2.00
10-A	Fd	3					71	4.23
11-A	Fd		2					
	Pl	1						
							58	5.17
11-B							33	0.00
12-A							131	0.00
13-A	Fd		1				59	1.69
Total		14	5	2	0	1		

						Average by diameter class	Average by stratum
Total trees by diameter class		861	450	169	64	18		
% blowdown by diameter class		1.63	1.11	1.18	0.00	0	0.98	1.68

[a] A blank space in the table is equal to zero.

Table II-6. Total stems/ha for Layers 2, 3, and 4; natural and advanced regeneration.

Stratum	Germinants number/ha	Advanced regeneration (number/ ha)			Natural regeneration (number/ ha))		Total all layers (number/ha)	% advanced	% natural
		Layer 2	Layer 3	Layer 4	Layer 3	Layer 4			
1-A	1333	66	255	489	100	733	1643	49.30	50.70
2-A	1000	133	667	2044	0	844	3688	77.11	22.89
2-B	2251	44	582	1612	13	626	2877	77.79	22.21
2-C	723	33	211	1123	0	178	1545	88.48	11.52
3-A	4222	89	399	600	44	3600	4732	22.99	77.01
3-B	1333	400	733	1433	0	567	3133	81.90	18.10
4-A	5200	20	20	5380	0	600	6020	90.03	9.97
5-A	9090	36	91	3182	0	1936	5245	63.09	36.91
5-B	7188	0	126	4150	0	1788	6064	70.51	29.49
5-C	8910	0	91	3381	0	2036	5508	63.04	36.96
5-D	8462	15	123	1600	0	4169	5907	29.42	70.58
6-A	3813	275	438	875	0	3751	5339	29.74	70.26
7-A	0	111	778	622	289	2045	3845	39.30	60.70
7-B	1444	44	467	1934	22	5000	7467	32.74	67.26
8-A	1200	200	1120	460	0	1800	3580	49.72	50.28
9-A	688	26	138	1938	0	225	2327	90.33	9.67
9-B	154	15	322	1108	0	369	1814	79.66	20.34
10-A	3750	83	283	500	0	3600	4466	19.39	80.61
11-A	4667	50	683	2050	350	1467	4600	60.50	39.50
11-B	7333	0	933	5156	667	911	7667	79.42	20.58
12-A	5294	24	342	1624	48	1764	3802	52.34	47.66
13-A	1369	63	452	1305	0	400	2220	81.98	18.02
Average	3610	79	421	1935	70	1746	4250	60.40	39.60

Table II-7. *q* values for Layers 2, 3, and 4

Stratum	*q* (3:2)	*q* (4:3)
1-A	5.4	3.4
2-A	5.0	4.3
2-B	13.5	3.8
2-C	6.3	6.2
3-A	4.9	9.4
3-B	1.8	2.7
4-A	1.0	–
5-A	2.5	56.2
5-B	0.0	47.1
5-C	0.0	59.5
5-D	8.2	46.9
6-A	1.6	10.6
7-A	9.6	2.5
7-B	11.1	14.2
8-A	5.6	2.0
9-A	5.3	15.7
9-B	21.5	4.6
10-A	3.4	14.5
11-A	13.7	5.1
11-B	0.0	6.5
12-A	14.5	9.9
13-A	7.1	3.8
Average *q*	6.5	15.7
Standard deviation *q*	5.6	18.9
Maximum *q*	21.5	59.5

Table II-8. Mean 5-year radial increment for Layer 1, by diameter class

Stratum	Radial increment by diameter class (dbh in cm)							Average (cm)
	18.5 cm	28.5 cm	38.5 cm	48.5 cm	58.5 cm	68.5 cm	78.5 cm	
1-A	0.94	0.84	1.67	0	1.11	0	0	1.14
2-A	0.86	0.99	0.86	0.94	1.48	1.50	0	1.11
2-B	1.06	1.16	1.03	0.92	1.22	0.75	0	1.02
2-C	0.90	0.90	0.61	0.83	1.40	0.55	1.55	0.96
3-A	0.74	0.86	0	0	0	0	0	0.80
3-B	0.44	0.60	0	0	0	0	0	0.52
4-A	0.5	0.64	0.73	0.67	0	0	0	0.64
5-A	0.56	0.82	0.71	0.77	0	0	0.40	0.65
5-B	0.76	0.79	0.79	0.55	0	0	0.40	0.66
5-C	0.84	1.15	1.10	1.00	0	0	0	1.02
5-D	0.52	0.89	0.90	0.80	0	0	0	0.78
6-A	0.68	1.21	0.48	0.40	1.40	0	0	0.83
7-A	1.28	0.71	1.04	0	0	0	0	1.01
7-B	1.04	0.84	0.88	1.79	0	0	0	1.14
8-A	0.99	1.01	0.93	0	0.64	0	0	0.89
9-A	1.10	1.27	1.07	0.33	1.08	0	0	0.97
9-B	1.14	1.35	1.17	0.58	1.17	0	0	1.08
10-A	1.08	0.97	0.83	0	0	0	0	0.96
11-A	0.94	0.95	0.82	1.36	0	0	0	1.02
11-B	1.03	1.76	0.93	1.21	0	0	0	1.23
12-A	0.98	1.65	0	0	0	0	0	1.32
13-A	1.22	1.28	1.14	0.95	1.10	1.50	0	1.20

Table II-9. Mean 5-year residual increment for Layer 1, by species.

Stratum	Species (cm)								
	At	Bl	Cw	Ep	Fd	Lw	Pl	Py	Sx
1-A					1.09	0.82			
2-A					1.15	0.62	0.28	1.07	
2-B					1.18	0.80	0.77	0.98	
2-C					0.88	0.83		1.20	
3-A					0.87	0.38	0.72	0.81	
3-B					0.54	0.27	0.44	0.45	
4-A					0.59			0.88	
5-A			0.70	0.50	0.77	0.52	0.40		
5-B		0.50		0.60	0.66	0.92			
5-C	0.20				0.93	1.25			
5-D					0.70	0.66			
6-A					0.88	0.57	0.30		
7-A					1.24			0.73	
7-B					1.30	0.42	0.71	0.92	
8-A					1.20	0.93	0.68	0.94	
9-A					1.27	1.28		0.93	
9-B					1.27	1.17		1.18	
10-A	0.92				1.03	1.25			
11-A					1.10		0.45		1.29
11-B					1.30				
12-A					1.73	0.84	0.88	0.98	1.06
13-A					1.49	1.05		0.92	

Table II-10. Residual stems/ha by stratum, and by 5-cm diameter class.

	Diameter class (mid range of 5-cm increments) (no.)																
Stratum	0.1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
1-A	1378	400	67	94	86	67	14	6	3	3		3	3				
2-A	2889	667	133	67	39	36	19	17	17	17	17	6	3	3			
2-B	2569	594	44	63	50	28	22	13	14	11	6	2	2	2			
2-C	1300	222	33	31	28	36	17	14	19	8	8	8		3			3
3-A	4200	444	89	83	72	94	50										
3-B	2000	733	400	250	175	92	83	8	25	8							
4-A	5980	20	20	75	40	60	30	30	10	10	5						
5-A	5418	91	36	93	45	41	32	48	23	11		2	2				2
5-B	6525	125		44	41	38	28	16	34	13	9						3
5-C	5455	109		82	27	36	18	9	5	5	5						
5-D	5815	123	15	58	89	54	15	4	4	12	8						
6-A	4663	438	275	153	86	9	34	16	25	6		3					
7-A	2667	1067	111	50	22	28	56	6	11								
7-B	6933	489	44	44	33	78	67	17	6	6							
8-A	2320	1120	200	100	45	30	35	25					5				
9-A	2883	288	38	84	66	53	19	25	9		3	3					
9-B	1615	323	15	35	54	62	12	12	12	4	4		4				
10-A	4383	283	83	138	117	29	13	8	4								
11-A	3600	1067	50	96	46	54	29	21	4	4							
11-B	6156	1600		61	61	28	17	11		6							
12-A	3506	435	35	141	129	91	24					3					
13-A	1832	453	63	32	37	32	21	24	3	5	3	3	3	3			
Avg.	3821.2	504.1	92.2	85.2	61.3	48.9	29.8	16.5	12.7	8.1	8.8	3.7	3.1	2.8	0.0	0.0	2.7
Min. value	1300.0	20.0	15.0	31.0	22.0	9.0	12.0	4.0	3.0	3.0	3.0	2.0	2.0	2.0	0.0	0.0	2.0
Max. value	6933.0	1600.0	400.0	250.0	175.0	94.0	83.0	48.0	34.0	17.0	17.0	8.0	5.0	3.0	0.0	0.0	3.0

[a] No residual stems in the 70-cm and 75-cm diameter classes were observed in any of the strata.

Table II-11. **Basal area of stumps, by species.**

Stratum	Species (m^2/ha)			
	Fd	Lw	Pl	Py
1-A	3.31	7.75	11.61	0
2-A	3.08	0.07	5.94	0
2-B	0.97	1.11	6.07	3.35
2-C	3.75	1.50	7.89	0.99
3-A	9.23	1.06	0.27	0.59
3-B	2.98	1.51	0	0
4-A	15.42	0	0	0
5-A	4.15	1.02	10.73	0
5-B	1.12	0.20	10.02	0
5-C	0.63	0	19.46	0
5-D	9.83	0.78	6.61	0
6-A	4.83	2.18	10.5	0
7-A	2.71	1.72	0	8.54
7-B	6.10	2.91	0	5.48
8-A	0	5.28	9.22	0.13
9-A	0.42	5.17	11.79	0
9-B	0.06	1.11	13.94	0
10-A	20.23	0	0.93	0
11-A	2.37	0	9.16	0
11-B	9.77	0	2.55	0
12-A	9.64	6.05	1.92	0.59
13-A	0.96	2.47	14.98	0.16

Table II-12. Basal area of stumps, by diameter class.

Stratum	Diameter class (dbh) (m^2/ha)						
	18.5 cm	28.5 cm	38.5 cm	48.5 cm	58.5 cm	68.5 cm	78.5 cm
1-A	11.66	4.16	0.92	1.04	2.05	2.84	0
2-A	6.09	1.97	1.03	0	0	0	0
2-B	2.39	2.88	1.42	1.37	1.59	1.06	0.79
2-C	6.38	4.46	1.46	0.43	1.40	0	0
3-A	0.42	4.72	5.22	0.79	0	0	0
3-B	0.74	0	0.95	2.79	0	0	0
4-A	12.05	3.37	0	0	0	0	0
5-A	10.67	4.07	0.60	0	0.55	0	0
5-B	10.48	0.86	0	0	0	0	0
5-C	18.95	1.21	0	0	0	0	0
5-D	11.85	5.11	0.34	0	0	0	0
6-A	10.49	4.85	1.01	0.46	0.70	0	0
7-A	0.37	5.48	5.25	1.86	0	0	0
7-B	0.32	7.50	6.67	0	0	0	0
8-A	6.51	4.19	2.10	0.74	1.09	0	0
9-A	7.81	5.40	1.03	0	0.88	2.27	0
9-B	10.09	4.16	0.85	0	0	0	0
10-A	15.99	5.22	0	0	0	0	0
11-A	4.45	5.32	1.12	0.64	0	0	0
11-B	3.31	4.14	2.71	0.89	1.29	0	0
12-A	2.89	6.71	3.46	2.71	1.41	0	1.24
13-A	10.72	5.18	1.76	0.92	0	0	0

TABLE II-13. Basal area harvested (stumps), as percent of basal area before harvest.

Stratum	Basal area			
	Pre-harvest (m^2/ha)	Post-harvest (m^2/ha)	Harvested	
			m^2/ha	%
1A	34.21	11.54	22.67	66.27
2A	27.68	18.59	9.09	32.83
2B	24.55	13.06	11.49	46.81
2C	29.42	15.29	14.13	48.02
3A	23.85	12.71	11.15	46.73
3B	32.07	27.59	4.49	13.99
4A	29.48	14.06	15.42	52.31
5A	34.88	18.99	15.89	45.55
5B	28.25	16.91	11.34	40.16
5C	28.52	8.35	20.16	70.71
5D	28.14	10.85	17.29	61.45
6A	31.38	13.86	17.51	55.82
7A	23.46	10.49	12.97	55.29
7B	28.34	13.85	14.49	51.13
8A	26.50	11.87	14.63	55.21
9A	30.03	12.65	17.38	57.88
9B	26.03	10.92	15.10	58.03
10A	31.56	10.34	21.22	67.23
11A	22.76	11.22	11.53	50.68
11B	20.98	8.65	12.33	58.76
12A	32.08	13.65	18.43	57.45
13A	30.04	11.47	18.58	61.83

Table II-14. Layers 2, 3, and 4 leader heights, for advanced and post-harvest regeneration.

Stratum	Layer 2, advanced (cm)	Layer 3 (cm)		Layer 4 (cm)	
		Advanced	Natural	Advanced	Natural
1A	17.6	12.2	34.0	8.9	11.4
2A	10.2	11.6	9.4	6.4	14.0
2B	10.0	14.7	14.0	5.6	6.4
2C	26.0	23.3	35.0	9.0	8.4
3A	10.3	7.7	8.0	6.7	4.2
3B	2.4	3.1	0.0	2.2	3.4
4A	4.0	4.0	0.0	4.6	4.5
5A	0.0	4.3	0.0	7.7	6.4
5B	0.0	12.2	0.0	9.0	10.4
5C	0.0	0.0	0.0	9.7	8.1
5D	2.0	0.0	0.0	8.6	9.3
6A	4.5	4.6	0.0	7.6	8.9
7A	37.0	16.2	22.7	7.4	8.0
7B	47.5	36.5	25.0	9.5	8.5
8A	45.0	14.4	0.0	2.0	5.5
9A	12.0	15.7	0.0	7.7	8.4
9B	13.0	18.4	0.0	15.8	12.0
10A	3.0	14.0	20.5	13.6	9.4
11A	11.0	19.8	23.2	7.4	8.5
11B	0.0	15.8	28.6	5.4	5.8
12A	14.3	16.8	23.3	7.3	7.0
13A	9.3	12.5	0.0	9.1	8.7
Average	12.7	12.6	11.1	7.8	8.1

TABLE II-15. Years to recover to pre-harvest basal area.

Stratum	5-yr basal area increment (m^2/ha)	Basal area harvested (m^2/ha)	Basal area increment/yr/ha (m^2/ha/yr)	Years to recover to pre-harvest basal area (no.)
1A	1.51	22.67	0.30	74.82
2A	1.89	9.09	0.38	24.02
2B	1.67	11.49	0.33	34.44
2C	1.38	14.13	0.28	51.06
3A	1.78	11.15	0.36	31.37
3B	1.93	4.49	0.39	11.63
4A	1.15	15.42	0.23	67.22
5A	1.67	15.89	0.33	47.71
5B	1.30	11.34	0.26	43.50
5C	1.11	20.16	0.22	90.66
5D	1.06	17.29	0.21	81.73
6A	1.53	17.51	0.31	57.26
7A	1.07	12.97	0.21	60.54
7B	1.73	14.49	0.35	41.98
8A	1.32	14.63	0.26	55.48
9A	1.75	17.38	0.35	49.80
9B	1.38	15.10	0.28	54.61
10A	1.79	21.22	0.36	59.24
11A	1.49	11.53	0.30	38.62
11B	1.47	12.33	0.29	41.88
12A	2.44	18.43	0.49	37.76
13A	1.48	18.58	0.30	62.64

APPENDIX III. List of Scientific Plant Names

Scientific name	Common name
Acer glabrum	Douglas maple
Achillea millefolium	yarrow
Amelanchier alnifolia	saskatoon
Antennaria microphylla	rosy pussytoes
Antennaria neglecta	field pussytoes
Arctostophylos uva-ursi	kinnikinnick
Ceanothus velutinus	snow brush, deer brush
Chimaphila umbellata	prince's pine
Juniperus communis	common juniper
Linnaea borealis	twinflower
Mahonia aquifolium	tall Oregon grape
Calamagrostis rubescens	pinegrass
Rosa acicularis	prickly rose
Salix species	willow species
Shepherdia canadensis	soopolallie, buffalo berry
Spiraea betulifolia	birch leaved spiraea
Symphoricarpos albus	snowberry
Vaccinium membranaceum	black huckleberry

From Braumandl and Curran 1999.